AD NUMBER

AD821495

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; 17 OCT 1967. Other requests shall be referred to Air Force Materials Lab., Wright-Patterson AFB, OH 45433.

AUTHORITY

AFML USAF ltr, 12 Jan 1972

DMIC

E

INTRODUCTION

This Review of Recent Developments on Aluminum and Magnesium represents the first issue of a new series dealing with the general metallurgy of these metals. Although aluminum and magnesium were not reviewed separately in the past, the behavior and properties of these metals and their alloys have been treated in other reviews such as those on corrosion, joining, mechanical properties, and metalworking.

SILVER ADDITIONS IN 7075-TYPE ALLOYS

The Boeing Company has reported on the effect of silver additions on the stress-corrosion, fatigue, and fracture properties of 7075-type alloys.(1) In the program, the factors studied included variations in copper, zinc, magnesium, and chromium contents, small additions of silver, boron, cerium, yttrium, and zirconium, and heat treatment. The most significant result of the study was the increased resistance to stress-corrosion cracking conferred on Alloy 7075-T6 by the addition of 0.44 percent silver. On the basis of the results of stress-corrosion tests, three effects were attributed to the presence of the silver additions: (1) the delay of crack initiation, (2) a reduced rate of crack growth, and (3) an increased susceptibility to pitting corrosion. Alloys containing silver additions were found to be similar to the usual 7075-alloy composition in that they were immune to stress-corrosion cracking when overaged (e.g., T6 plus 10 hours at 320 F). In the overaged condition, the increased susceptibility to pitting attack of the alloys containing silver resulted in the failure of these alloys before failure of the ordinary 7075 composition. Results obtained from the exposure of overaged and stressed specimens in an alternate immersion test (3 percent NaCl solution), indicated that specimens containing about 0.2 percent silver were less susceptible to pitting attack than were alloys containing 0.44 percent silver.

The effects of silver additions and other variations of composition also were studied in terms of tensile properties, fatigue crack-growth rate, and fracture toughness. The silver additions produced tensile strengths higher than those of the ordinary 7075 composition (Table 1). The increase in tensile properties associated with silver additions was observed in all the heat-treated conditions examined — the T6, maximum aged hardness, and the overaged conditions (T6 plus 10 or 30 hours at 320 F). Limited tests indicated that crack-growth rates during fatigue testing in an environment of distilled water were about 11 percent higher for alloys containing silver than for similar compositions without silver addition. The effect of silver additions on fracture toughness of alloys in the T6 condition was considered to be generally beneficial; however, silver additions were detrimental to fracture toughness in experimental alloys with a low zinc/magnesium ratio. Also, silver additions were found to increase the quench sensitivity of the 7075 composition, i.e., equal or superior properties were achieved only when high cooling rates were operative, as found in thin sections. The effects attributed to silver additions were found to be consistent in material produced under plant conditions by two different suppliers.

Of the other factors studied in this work, higher copper contents were found to produce lower rates of fatigue-crack propagation and zinc/magnesium ratios of 2.5 or more were associated with superior fracture-toughness values. Zirconium additions (0.10 percent) appeared to produce a slight increase in fracture-toughness values.

WELDABLE ALUMINUM PLATE ALLOYS

A continuing program at Alcoa Research Laboratories is devoted to the development of the aluminum alloys X2021 and X7007 for application as welded thick plate at cryogenic temperatures.(2,3) The target properties of this program included 75 ksi minimum tensile strength, 65 ksi minimum yield strength, 10 percent minimum elongation at room temperature and -423 F with very low notch sensitivity, 80 percent weld-joint efficiency, and maximum resistance to corrosion and stress corrosion. Most of the target properties have been met or approached in plate thicknesses up to 1 inch. The major problems encountered were those of weld-joint efficiencies in both alloys, and stress-corrosion cracking, notch sensitivity, and lack of low-temperature weld ductility in the X7007 alloy.

The tentative nominal compositions so far developed for these two alloys are as follows:

	X2021	X7007
Si	0.20 max	Si + Fe 0.40 max
Fe	0.30 max	—
Cu	6.3	0.10
Mn	0.3	0.2
Mg	0.02 max	1.8
Cr	—	0.12
Zn	0.10 max	6.5
Ti	0.06	0.04
Zr	0.18	0.12
V	0.10	—
Cd	0.15	—
Sn	0.05	—
Other	0.15 max	0.15 max

TABLE 1. THE EFFECTS OF VARIATIONS IN COMPOSITION ON THE PROPERTIES OF 7075-TYPE ALLOYS, SOLUTION HEAT TREATED, QUENCHED, AND AGED(a) TO PRODUCE MAXIMUM STRENGTH(1)

Alloy Composition, weight percent						Ultimate Tensile Strength,	Tensile Yield Strength,	Elongation,	K_c,
Zn	Mg	Cu	Ag	Zr	Zn/Mg Ratio	ksi	ksi	percent	ksi $\sqrt{in.}$
5.6	2.5	1.4	—	—	2.24	76.0	66.7	6	—
5.7	2.5	1.4	0.44	—	2.28	78.3	69.0	10	—
5.6	2.5	1.4	0.44	0.10	2.24	79.4	73.0	10	—
6.4	1.6	1.4	—	—	4.00	74.6	67.9	16	99.1
5.2	2.3	1.4	—	—	2.26	76.1	68.2	15	96.8
4.5	3.0	1.4	—	—	1.50	78.5	70.7	14	78.9
6.3	1.6	1.4	—	—	3.94	73.6	65.3	16	98.9
6.3	1.7	1.4	0.44	—	3.71	80.6	73.4	14	94.5
5.1	2.2	1.4	0.45	—	2.32	79.3	71.7	16	93.7
4.5	2.9	1.4	0.44	—	1.55	78.5	70.8	14	55.8
6.4	1.7	1.4	0.44	0.10	3.76	78.8	71.4	16	102.8

(a) Aged either 36 or 48 hours at 250 F.

However, recent studies have established that a specification of a r imum of 0.01 percent magnesium in Alloy X2021 would guarantee maximum aged strength. Further, current work has indicated that the zirconium content in Alloy X2021 is responsible for a high-quench sensitivity. Also included in current work on composition variations was a study of the effects of additions of 0.2, 0.3, or 0.4 percent silver on the stress-corrosion cracking behavior of Alloy X7007. Silver additions improved the resistance of the alloy to stress-corrosion cracking when exposed to an industrial atmosphere, but had no such benefit in a 3-1/2 percent NaCl alternate immersion test.

The development of these two alloys has included the evolution of heat treatments to achieve the standard T6-type condition as well as special heat treatments and tempers adapted to the alloys. The processes established so far are as follows:

Alloy	Temper Designation	Solution Heat Treatment, Temp, F	Pre-Age Treatment Time, hr	Pre-Age Treatment Temp, F	Pre-Age Treatment Stretch, percent	Aging Treatment Time, hr	Aging Treatment Temp, F
X2021	T6	995	—	—	—	16	325
X2021	T6E31	995	1	300	1.5	12	325
X7007	T6	860	—	—	—	8	225
						16	300

Welding materials are being evaluated on joints made with experimental aluminum-copper-magnesium alloys as well as 2319 for use as filler metal. The use of the experimental filler alloys resulted in joint tensile strengths of about 40 ksi compared with 35 ksi achieved with 2319 filler metal.

BRAZED HIGH-STRENGTH ALUMINUM-ALLOY HONEYCOMB

A 3-year development program for NASA was conducted by Aeronca to develop materials and fabrication methods for producing high-strength aluminum-alloy honeycomb suitable for applications from -423 to 600 F.(4,5) The program included development of fabrication methods using currently available aluminum alloys as well as investigation of new compositions of brazing alloys suitable for use with the higher strength aluminum alloys.

Panels 24 x 30 inches in size, both flat and cylindrical, were produced using X7005 and X7106 face sheets, X7005 core, and No. 719 brazing alloy, and their properties were evaluated at temperatures of -423 to 600 F. Some of the properties measured on these panels are listed in Table 2. The core materials were fabricated to a core density of approximately 6 to 8 lb/ft^3. All brazing was done in an argon atmosphere. Also demonstrated was the feasibility of quenching the brazed honeycomb assembly in liquid nitrogen to minimize distortion and to achieve quenching rates commensurate with high-strength heat-treatable alloys. The honeycomb with X7005-alloy face sheets was quenched directly from the brazing operation (at 1050 to 1075 F) and subsequently aged, while the honeycomb with X7106-alloy face sheets was brazed and subsequently solution heat treated (875 F) and aged.

An additional portion of the program involved the development of brazing alloys with melting points more suitable for use with the X7005 and X7106 alloys. After the study of a considerable number of compositions, two were considered most nearly optimum for use with these alloys: 68Al-15Ge-7Si-10Zn and 68Al-15Ge-7Si-10Ag. The alloy containing zinc produced better quality honeycomb under the brazing conditions used and had very little degrading effect on the properties of the sheet alloy. In the study using the alloy containing silver, the brazing temperature was apparently too high since considerable interdiffusion of the brazing alloy with the sheet alloy occurred.

DESIGN PROPERTIES OF ALLOY 7001-T75

The results of an extensive evaluation of the properties of aluminum alloy 7001-T75 have been published.(6) The T75 temper is a proprietary heat-treated condition developed by Harvey Aluminum Company. Samples of sheet, plate, extrusions, hand forgings, and die forgings were evaluated by 10 aerospace companies for the purpose of establishing design criteria. The properties of 7001-T75 were, in most cases, compared directly with similar test results for 7075-T6, 7178-T6, and 7178-T76. In general, the mechanical properties of 7001-T75 fell between the "minimum" and "typical" properties of 7075-T6. These mechanical properties were accompanied by higher resistance of 7001-T75 than 7075-T6 to both stress-corrosion cracking and exfoliation corrosion. Most evaluators concluded that 7001-T75 was a candidate for substitution in applications

TABLE 2. RESULTS OF SOME ROOM-TEMPERATURE TESTS OF HIGH-STRENGTH ALUMINUM-ALLOY HONEYCOMB[illegible]

Face Sheet Alloy	Core Alloy	Brazing Alloy	Type Core	Edgewise Compression Test, Face Sheet Stress at Failure, psi	Flatwise Tensile Test, Failing Stress, psi	Flatwise Compression Test, Failing Stress, psi	Core Shear Stress, psi
X7005	X7005	719	6-80 x 1/2 in.	59,000	1,200	1,380	867
X7106	6951	716	6-80 x 1/2 in.	45,000	676	516	308
7039	6951	719	6-80 x 1/2 in.	42,300	[illegible]	852	493
X7005	X7005	719	6-50 x 1/2 in.	51,000	860	770	500
X7106	X7005	719	6-50 x 1/2 in.	[illegible]	980	1,000	580
X7106	X7005	719	5-50 x 1/2 in.	61,000	1,140	[illegible]	635
X7106	X7005	Al-Ge-Si-Zn	6-50 x 1/2 in.	56,200	540	575	470

calling for the properties of 7075-T6 and requiring better resistance to stress-corrosion cracking.

HYDRIDE STRENGTHENING OF MAGNESIUM ALLOYS

Magnesium Elektron, Ltd., has developed two magnesium-zinc-rare earth casting alloys susceptible to strengthening by the formation of rare-earth hydrides during heat treatment in a hydrogen atmosphere.(7) Two alloy compositions have been recommended as suitable for such a system: (1) 5.5-6.0Zn, 2.0-3.0 rare-earth metals, 0.4Zn, balance magnesium and (2) the same composition plus 0.75-1.25Ag. These alloy compositions are designated as ZE63A and ZE63B, respectively. The heat treatments for these alloys consist of a solution treatment-hydriding treatment at 890 F for ZE63A or 860 F for ZE63B. Times are varied from 30 hours for 1/2-inch-thick sections to 70 hours for 3/4- to 1-inch-thick sections. After quenching from the solution treatment, aging is performed at 260 F for 72 hours.

The tensile properties obtainable in these alloys are indicated in Table 3, which compares tensile minima for premium-quality castings, Class 1, for ZK61A and QE22A with the corresponding tentative minima for ZE63A and with properties of a chilled casting of ZE63B. The comparison of tensile properties must be qualified by the following conditions: (1) ZE63A has slightly better yield strength and elongation than QE22A, and does not contain the relatively expensive 2 percent silver addition present in QE22A; (2) ZE63A has about the same strength and elongation as ZK61A, but offers the advantages of being weldable and of exhibiting greater freedom from porosity and shrinkage; and (3) ZE63B has the highest tensile properties of the alloys compared, is also weldable and highly castable, but contains a silver addition. In addition, these alloys offer the advantages of high fatigue strengths relative to their tensile strengths, corrosion resistances similar to other magnesium alloys, and compatibility with standard coating systems. Unusual features of the alloys are the long-time heat treatment in hydrogen required for hydriding, and the associated restriction to section thicknesses of about 1 inch or less. The strengthening achieved in these alloys is attributed to the decomposition of zinc-rare earth compounds in the alloy during hydride formation, making the zinc available for strengthening.

TABLE 3. TENSILE PROPERTIES OF SOME MAGNESIUM ALLOYS(7)

Alloy	Tensile Yield Strength, 0.2% offset, psi	Ultimate Tensile Strength, psi	Elongation, % in 2 inches
ZK61A	29,000	42,000	6
QE22A	28,000	40,000	4
ZE63A	28,000	42,000	6
ZE63B	33,200	49,300	15

MAGNESIUM-YTTRIUM ALLOYS

Frankford Arsenal has published the results of a study of the aging behavior of magnesium-yttrium alloys.(8) Alloys containing 8.2, 9.0, and 10.6 percent yttrium in the form of rolled sheet were studied for age-hardening response. Specimens were solution heat treated at 975 F, water quenched, and aged at 300, 345, 390, or 435 F for up to 16 days. Some age hardening occurred in all three alloys, but maximum strengths were found in the Mg-10.6Y alloy. An as-rolled specimen aged 4 days at 392 F had a yield strength of 55.1 ksi and an elongation of 2 percent. Although magnesium-base alloys generally exhibit considerable differences in tensile and compressive yield strengths, the values found in the Mg-10Y alloy were 55 ksi for tensile yield and 45 ksi for compressive yield in sheet rolled and aged at 392 F.

MAGNESIUM-LITHIUM ALLOY

The Frankford Arsenal program on magnesium-lithium-type alloy castings has been continued to include the development of foundry techniques for the production of lightweight castings.(9) Castings of a Mg-14Li-0.5Si alloy were produced by a new pouring method referred to as the "counter-gravity technique". As applied to these castings, the technique involved the use of the pressure of the protective argon atmosphere over the melt to force the molten metal up a pipe from the crucible into a sealed* mold on top of the furnace. The principal features of the technique included the use of a mold material of graphite particles bonded with water and bentonite, the use of fan and ring gates, and the use of insulating sleeves in the blind risers. Castings of three components typical of space-ve[illegible] parts were produced up to 2 pounds in weight w[illegible] wall thicknesses ranging from 1/8 to 1 inch. [illegible]stings were produced in the two alloy variations, Mg-14Li-0.3Si and Mg-14Li-0.9Si. Test bars cut from castings and separately cast test bars were similar in strength with the following approximate tensile properties:

*Apparently, the argon gas within is permitted to escape as the molten metal fills the mold.

	Mg-14Li-0.3Si	Mg-14Li-0.5Si
Ultimate Tensile Strength, psi	15,000	18,200
Tensile Yield Strength, psi	9,500	13,300
Elongation, percent	10 to 35	[illegible]

REFERENCES

(1) Hyatt, M.V., and Quist, W. E., "The Influence of Heat Treatment and Composition on the Stress Corrosion, Fatigue, and Fracture Properties of 7075-Type Aluminum Alloys", The Boeing Company, Seattle, Wash., paper presented at the AFML 50th Anniversary Corrosion of Military and Aerospace Equipment Technical Conference, Denver, Colo., May 23-25, 1967, DMIC No. 69246.

(2) Westerlund, R. W., and Rodgers, R. W., Jr., "Development of A High Strength Aluminum Alloy, Readily Weldable in Plate Thicknesses, and Suitable for Application at -423 F (-253 C)", Annual Report, Alcoa Research Laboratories, Aluminum Company of America, New Kensington, Pa., Contract NAS 8-5452 (April, 1967) DMIC No. 68621.

(3) Preliminary information reported by Alcoa Research Laboratories, Aluminum Company of America, New Kensington, Pa., under NASA Contract NAS 8-5452.

(4) Kramer, B. E., and Potter, D. Y., "Development of High Strength, Brazed Aluminum Honeycomb Sandwich Composites Adaptable for Both Elevated and Cryogenic Temperature Applications -- Volume 1 - Brazing Alloy", Final Report ER 986, Aeronca, Inc., Middletown, O., Contract NAS 8-5445 (September 30, 1966) DMIC No. 68066.

(5) Kramer, B. E., and Potter, D. Y., "Development of High Strength, Brazed Aluminum Honeycomb Sandwich Composites Adaptable for Both Elevated and Cryogenic Temperature Applications -- Volume II - Manufacturing and Testing", Final Report ER 986, Aeronca, Inc., Middletown, O., Contract NAS 8-5445 (September 30, 1966) DMIC No. 68067.

(6) Cicinella, A., "Evaluation of Aluminum Alloy 7001-T75", Technical Report No. 101, Aerospace Industries Association of America, Inc., Washington, D. C. (December, 1966) DMIC No. 68366.

(7) Fisher, P. A., Meredith, P. C., and Thomas, P. E., "New High Strength Magnesium Casting Alloys for Aerospace Applications", Magnesium Elektron, Ltd., Manchester, England, paper presented at the SAE Aeronautic & Space Engineering and Manufacturing Meeting, Los Angeles, Calif. (October, 1966) DMIC No. 66669.

(8) London, R. V., Edelman, R. E., and Markus, H., "Development of A Wrought High-Strength Magnesium-Yttrium Alloy", Report A66-13, Frankford Arsenal, Philadelphia, Pa. (June, 1966) DMIC No. 68589.

(9) Saia, A., Edelman, R. E., and Gilmore, H. L., "The Gating and Risering of Counter-Gravity Poured Magnesium-Lithium Castings", Modern Casting, pp 105-114 (July, 1967) DMIC No. 69032.

DMIC Reviews of Recent Developments present brief summaries of information which has become available to DMIC in the preceding period (usually 3 months), in each of several categories. DMIC does not intend that these reviews be made a part of the permanent technical literature. Copies of referenced reports are not available from DMIC; most can be obtained from the Defense Documentation Center, Cameron Station, Alexandria, Virginia 22314.

R. W. Endebrock, Editor